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Final Report

8/1/86 - 7/31/88

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"INSTRUMENTATION FOR LASER-BASED FLOWFIELD IMAGING AND FLOW FACILITIES FOR DIAGNOSTICS RESEARCH"

AFOSR 86-0272

Principal Investigator:
Professor Ronald K. Hanson
Department of Mechanical Engineering

Summary

This award has enabled acquisition of four state-of-the-art items of experimental apparatus to be used in research on diagnostics for combustion and plasma flows: a tunable excimer laser, a solid-state intensified camera system, a plasma diagnostics facility, and a laser-photolysis shock tube apparatus. All four systems are now operational and performing at or above initial expectations.

System Description/Status

Brief descriptions of the four equipment systems acquired are given below, followed by a discussion of current experiments.

(a) Laser System II: This is a tunable, high-pulse-power excimer laser system. The primary component is a model 160 MSC laser from Lambda-Physik. This is a state-of-the-art laser (the Stanford laser was the first unit delivered in the U.S.) which will enable efficient fluorescence excitation of O_2, NO and O, critical species for several of our ongoing experiments in laser diagnostics and supersonic combustion. The laser is capable of operation in narrow (about 1 nm) spectral windows at 193, 248, 308 and 351 nm. We have recently extended the number of spectral windows substantially by adding a Raman shifter into the system, thereby allowing operation at several discrete shifted wavelengths (Stokes and anti-Stokes shifts associated with the vibrational frequency of the cell gas, usually H_2 or D_2) adjacent to the above-listed wavelengths. The laser is now in use and is performing well.

(b) Camera System I: This is a new solid-state camera system which allows convenient use of multiple camera heads based on scientific-grade video camera technology. The sensors operate both with and without intensification, and the system is coupled to our laboratory computer network (Sun 3 and Pixar computers) to facilitate transfer of image data to image processing and display facilities. This overall system also includes a fast-framing camera (image converter) which enables rapid acquisition of multiple planar images to form 3-d image data sets. The system is complete and both the video camera and fast-framing camera are in use in current experiments.

(c) Plasma Diagnostics System (Flow Facility I): This is an instrumentation package to allow spectroscopic measurements in low and high pressure laboratory plasmas. The package includes optical and electronic components which complement the laser equipment already available in the laboratory and will enable, in particular, investigation of laser fluorescence imaging diagnostics for plasma flows. In addition, the system includes RF-powered atmospheric-pressure and low-pressure plasma facilities which provide the working

environment for our research on laser-based plasma diagnostics. The equipment is now completely installed and is being used to investigate new diagnostics approaches for monitoring electron density, gas temperature and velocity.

(d) Flow Facility IV: This is an instrumented test section for laser-photolysis experiments in the reflected shock region of a shock tube. The objective is to utilize a pulsed excimer laser to photolyze shock-heated gases and thereby perturb the chemical composition in a manner which will allow direct studies of high temperature gases. The system is now complete, and work based on its initial use has already been submitted for publication.

System Location

These systems are located in the High Temperature Gasdynamics Laboratory, building 570 on the Stanford campus.

Current Research

In this section, we give brief examples of current uses of the equipment purchased under this grant.

(a) Laser System II:

This laser system is currently employed in two PLIF diagnostics projects: (1) laser ignition; and (2) shock tube imaging. In the laser ignition work, we are using one excimer laser to ignite a flowing mixture of methane and air, and a second excimer laser serves as the tunable source needed to excite fluorescence from OH, CH or other species. The research is concerned with establishing a diagnostic which allows detailed probing of the full sequence of the ignition process: laser-induced breakdown, plasma heating, shock wave propagation, and flame front propagation. This is the thesis project of Jerry Seitzman. The second current excimer laser project is concerned with developing diagnostics approaches for PLIF imaging in shock-heated flows. We've constructed a square shock tube suited for imaging, and we've solved critical problems of synchronizing the shock position, laser pulse and intensifier gate pulse. Initial results have been obtained for incident and reflected shocks in O_2-seeded gases which illustrate the potential of PLIF for monitoring detailed 3-d flow structures in supersonic systems. We plan now to modify the shock tube to include a shock tunnel. This is the thesis work of Brian McMillin.

(b) Camera System I

This system has two primary configurations, one emphasizing video-compatible cameras and one involving a very fast image converter camera. In the video camera case, we have assembled the first intensified CCD camera and we have developed the software/hardware needed to incorporate multiple cameras into a single-computer-controlled system. As an example of its current research applications, we have used this camera to acquire PLIF images of OH in a small-scale supersonic combustor. The combustor operates on H_2 with air as the oxidizer. A schematic of the arrangement and typical results is shown in Fig. 1.

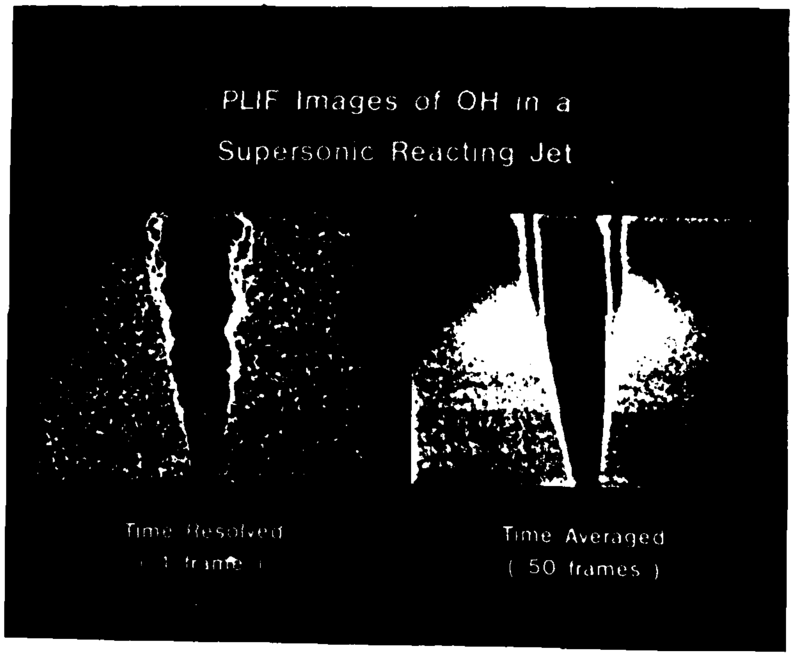
(c) Plasma Diagnostics System (Flow Facility I)

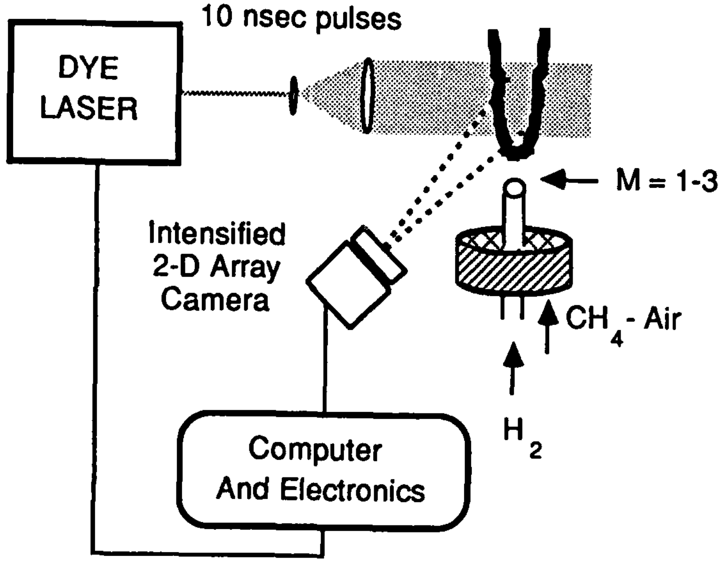
This system has both low-pressure and high-pressure plasma configurations. As an example of current research, the high-pressure system is being used to investigate plasma diagnostic concepts based on laser-wavelength modulation ideas. The plasma is a small-scale RF-powered torch which provides good optical access. The gases introduced are H_2 and argon. A cw dye laser is scanned in wavelength across the H-alpha transition of H at 656 nm, and the fluorescence (recorded at 90° to the laser beam) is used to monitor the Stark-broadened linewidths. Sample results are shown in Fig. 2; the electron density for this case is $3x10^{16}$ cm^{-3}. Further work is in progress to use these fully resolved lineshapes to infer the gas temperature which is expected to be about 6-8000 K.

(d) Laser-Photolysis Shock Tube (Flow Facility IV)

This new facility is now actively used for a combination of spectroscopic and kinetics topics. At present the excitation laser is an argon fluoride laser at 193 nm, and the gases excited are either NH_3, H_2O, NO or HNCO. The pulsed laser acts to instantly photodissociate the seed gas, thereby producing controlled levels of reactive radicals. The experiments involve measuring fundamental spectroscopic parameters such as oscillator strengths and collision-broadening parameters or determining reaction rate coefficients for elementary reactions involving the radical species. A schematic and sample result obtained with this system is shown in Fig. 3.

PULSED LIF IMAGING PROVIDES TIME-RESOLVED SPECIES MEASUREMENTS IN SUPERSONIC COMBUSTION





- Well-Suited for Fundamental Studies of Supersonic Mixing and Combustion
- Reveals Chemistry-Flow Structure Interactions Absent in Time-Averaged Images
- Data Rate of 7.5 Million Pixels Per Second; Framing Rate of 60 Hz

Figure 1. Example application of Camera System I.

Hanson/Stanford

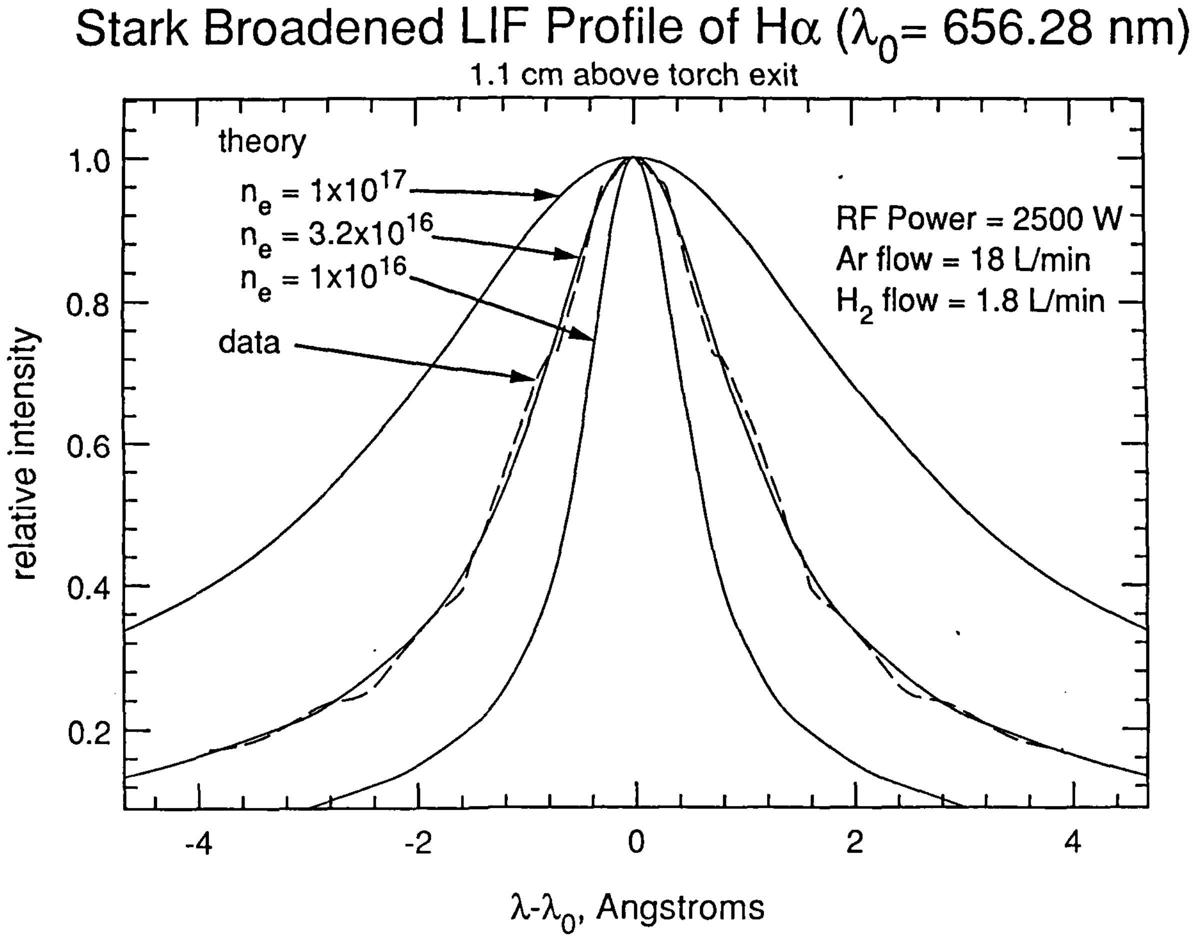
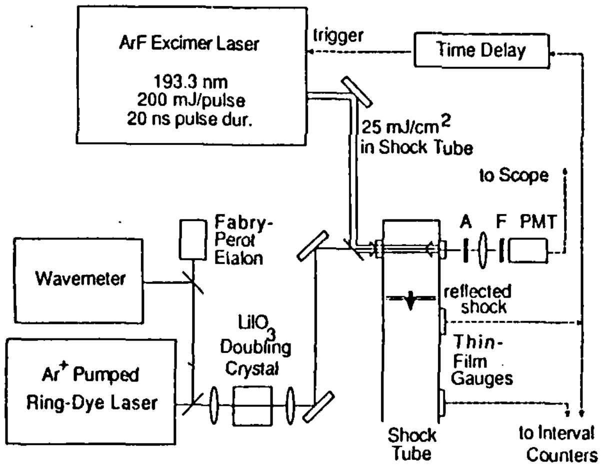
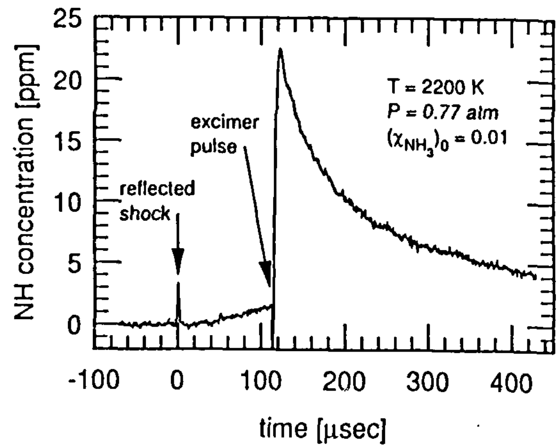


Figure 2. Example results obtained in atmospheric-pressure RF torch (Flow Facility I).

LASER PHOTOLYSIS SHOCK TUBE FOR FUNDAMENTAL STUDIES OF COMBUSTION RADICALS

- EXCIMER PHOTOLYSIS PROVIDES CONTROLLED POOL OF RADICALS IN SHOCK-HEATED GASES





- PROVIDES FIRST-TIME ACCESS TO MANY CRITICAL COMBUSTION SPECIES
- ENABLES FUNDAMENTAL SPECTROSCOPIC STUDIES OF RADICALS AT HIGH TEMPERATURES
- ENABLES FUNDAMENTAL KINETICS STUDIES OF RADICALS AT HIGH TEMPERATURES

Figure 3. Set-up and example results for Flow Facility IV.

System Expenditures

Approximate expenditure figures for the four equipment items are listed below:

Laser System II	$143,000
Camera System I	170,000
Plasma Diagnostics System	22,000
Laser-Photolysis Shock Tube	67,000
	$402,000

Note that this total exceeds the funds provided by AFOSR ($385,186) by $17,000. The necessary supplemental funding was provided by Stanford University gift funds.